Projected Changes in Land-Atmosphere Interactions from CMIP5 Simulations

Paul Dirmeyer

Yan Jin, Bohar Singh and Xiaoqin Yan

Climate Dynamics Program

George Mason University

Fairfax, Virginia

Result of a class term project in CLIM714: Land-Climate Interactions at GMU

CMIP5 Quandary

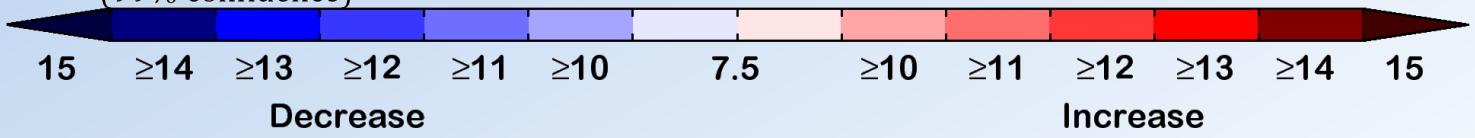
- When looking at results from many models, one usually finds one or more that are outliers or exhibit *peculiar* behavior, typically for a few but not all variables.
- Including the outliers in a multi-model mean skews results.
- There is no objective way to screen out "oddballs" that is not arbitrary.
- There is insufficient data (and for climate projects, no validation data) to construct unequal weights for various models.

One Model – One Vote

- Our solution is to treat the projected change in any variable at each point by each model as a binary result (+ or -) without regard to magnitude.
- Null hypothesis: equal odds for either outcome.
- This prevents an outlier, no matter how extreme, from having any more influence than any other model on the multi-model result.
- It also greatly simplifies the estimation of statistical significance…

15 Models Are Like 15 Coins…

Count:	0, 15	1, 14	2, 13	3, 12	4, 11	5, 10	6, 9	7, 8
Local Significance								
Probability	0.00003	0.00046	0.0032	0.0139	0.0417	0.0916	0.153	0.196
Cumulative Probability	0.00003	0.00049	0.0037	0.0175	0.0592	0.151	0.304	0.500
Global (Field) Significance								
Exceedance of expected value (99% confidence)	153x	17.7x	5.03x	2.55x	1.75x	1.42x	1.26x	1.17x
%Area of globe (99% confidence)	0.46%	0.87%	1.86%	4.47%	10.3%	21.5%	38.4%	58.5%



- The likelihood of n models agreeing at any point is analogous to n coin tosses agreeing.
- With an estimate of spatial DOFs, we can say if the area covered by a certain level of agreement is significant.

Models Used

- 95y monthly data from pre-industrial, historical and RCP8.5.
- Selection based on availability of required variables in COLA's CMIP5 archive.
- Only first ensemble member used.
- More than one version of some models.

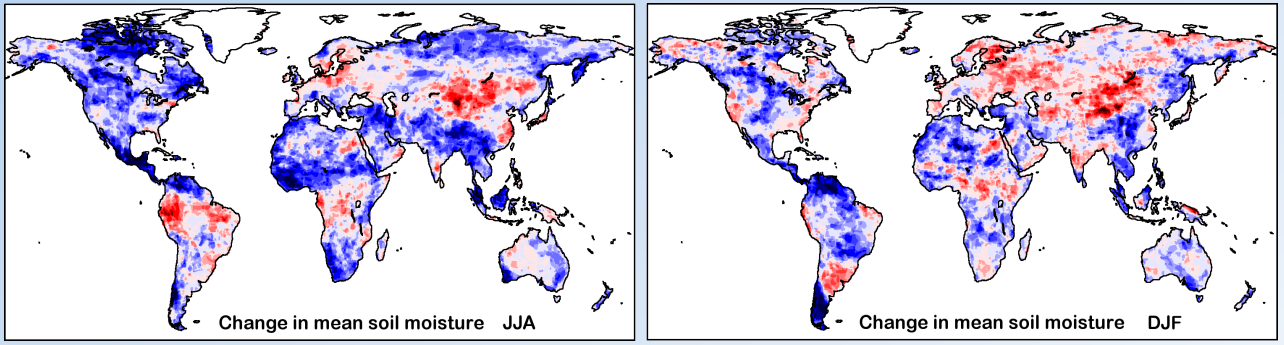
Center	Model Version	Resolution
Canadian Centre for Climate Modelling and Analysis	CanESM2	128 x 64
Centre National de Recherches Météorologiques / Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique	CNRM-CM5	256 x 128
Commonwealth Scientific and Industrial Research Organisation -Bureau of Meteorology	ACCESS1-0	192 x 145
Institute for Numerical Mathematics	INM-CM4	180 x 120
Institut Pierre-Simon Laplace	IPSL-CM5A-LR	96 x 96
	IPSL-CM5A-MR	144 x 143
University of Tokyo Division of Climate System Research	MIROC-ESM	128 x 64
	MIROC-ESM-CHEM	128 x 64
	MIROC5	256 x 128
Met Office Hadley Centre	HadGEM2-CC	192 x 145
	HadGEM2-ES	192 x 145
Meteorological Research Institute, Japan Meteorological Agency	MRI-CGCM3	320 x 160
NASA-Goddard Inistitue for Space Studies	GISS-E2-R	144 x 90
Norwegian Climate Centre	NorESM1-M	144 x 96
NOAA-Geophysical Fluid Dynamics Laboratory	GFDL-ESM2M	144 x 90

Land State

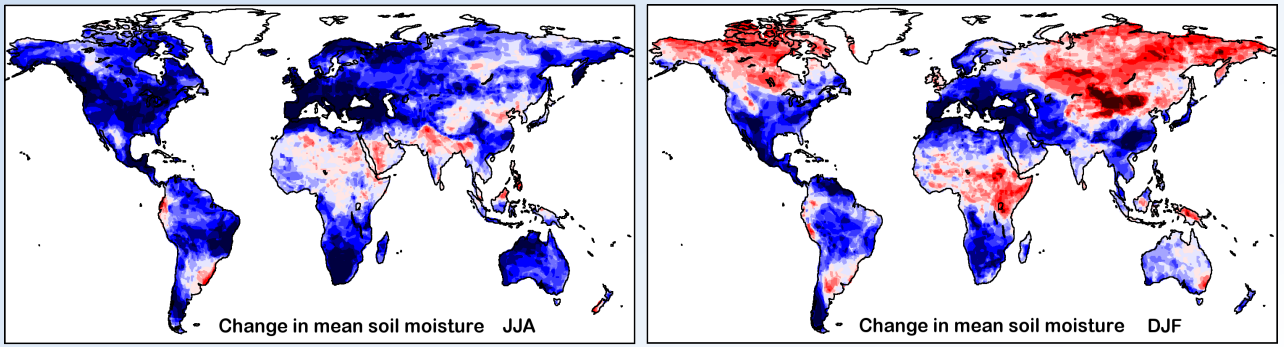
- Model consensus: 19th→20th century predominantly drying except central Asia.
- Future: severe drying globally in JJA; wetter at high latitudes and E. Africa in DJF.

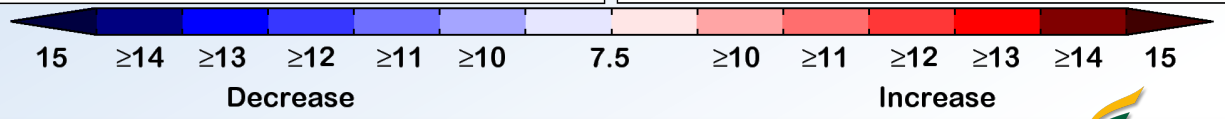
Soil Moisture in Top 10cm

Present [historical] minus Past [preIndustrial]



Future [RCP8.5] minus Present [historical]





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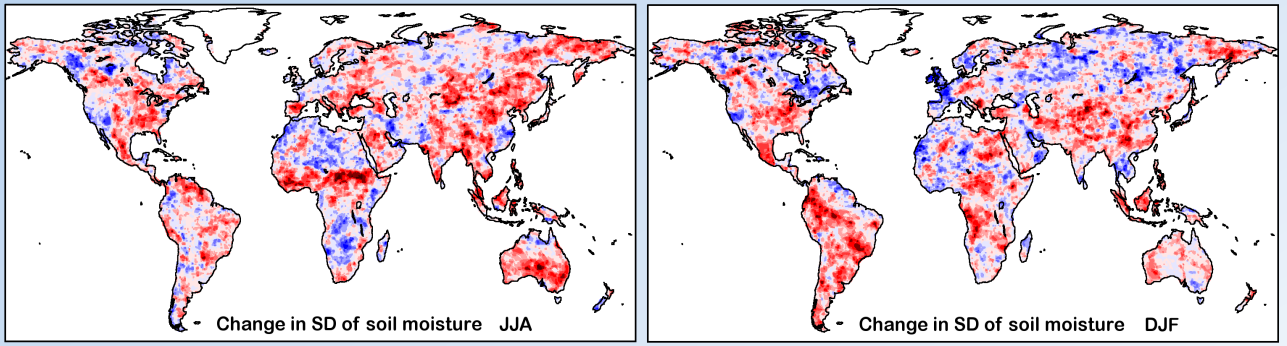
Variability

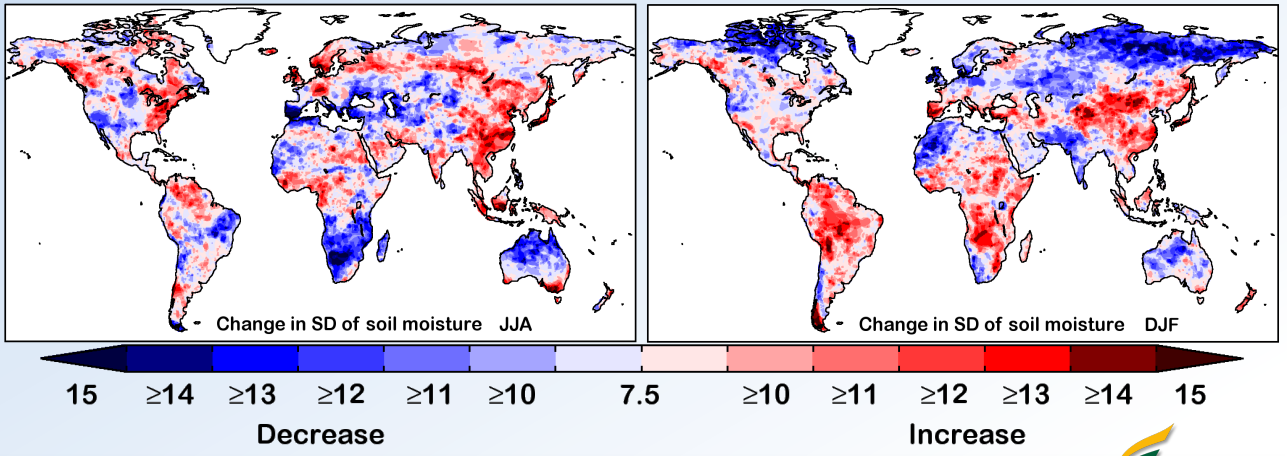
- Past: consensus that variability has increased.
- Future: more variability in many areas, but reduced in arid regions, dry seasons, and in winter at high latitudes.

Interannual σ Soil Moisture

Present [historical] minus Past [preIndustrial]



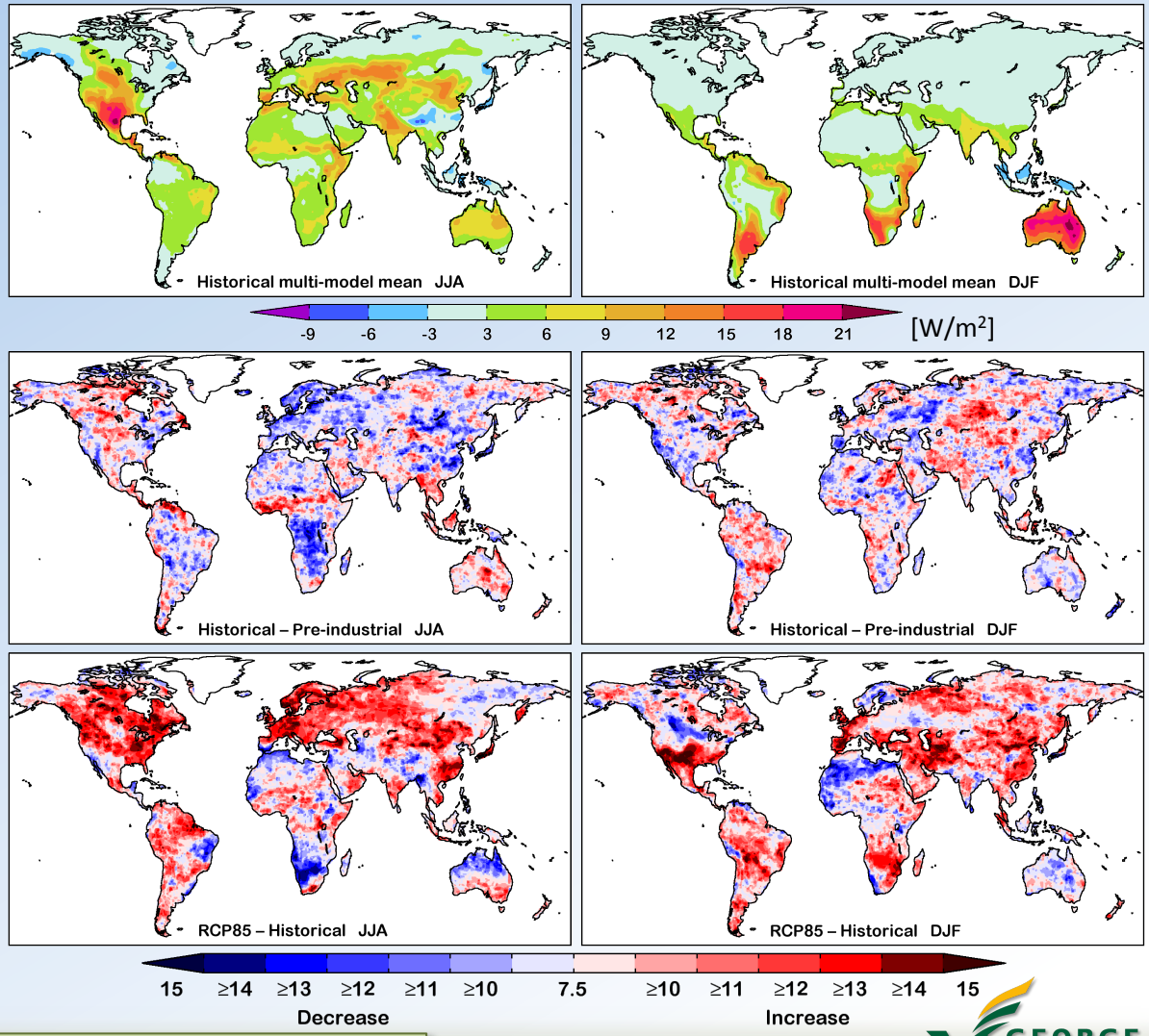
Future [RCP8.5] minus Present [historical]



L-A Coupling

$$I(w_m, \lambda E_m) = \lambda \frac{\sum (w'_{m,y} E'_{m,y})}{\sqrt{\sum (w'_{m,y})^2}}$$

- Corresponds strongly to “hot spots”.
- Global changes not field-significant past-to-present.
- Future: large areas of increased soil moisture control of surface fluxes.



Dirmeyer, 2011: *Geophys. Res. Lett.*, **38**, L16702, doi: 10.1029/2011GL048268.

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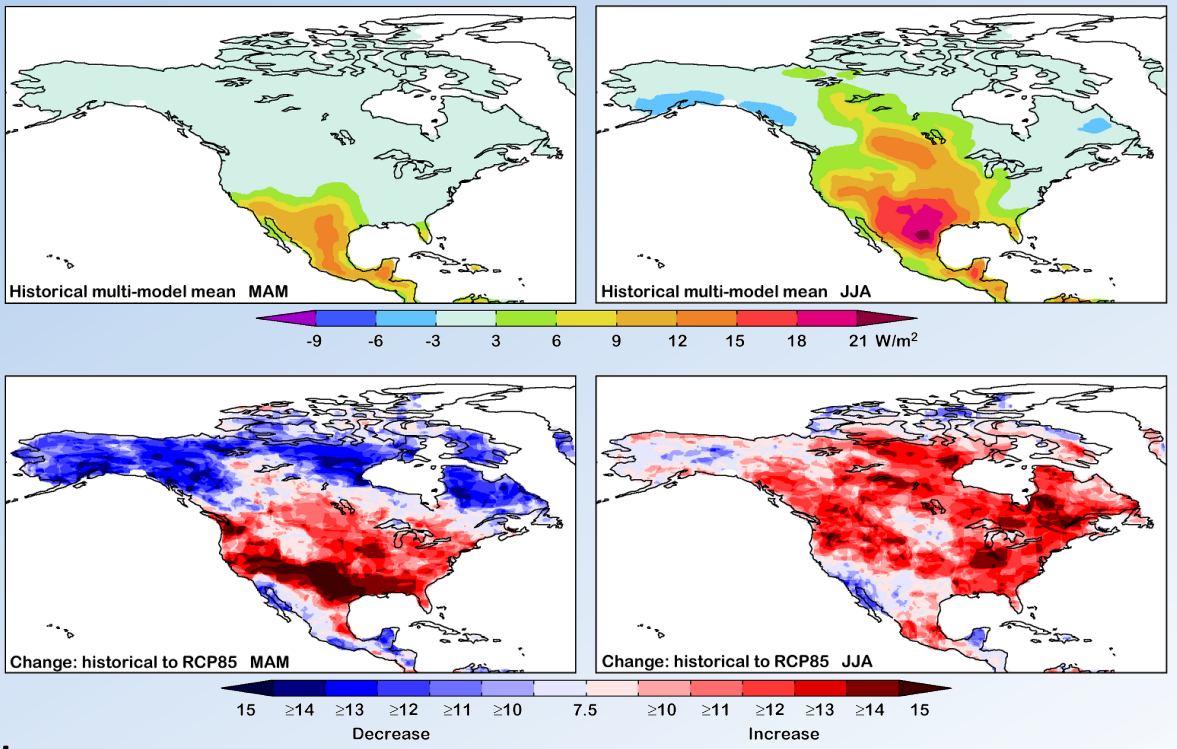
Evolution

- Present: strong L-A coupling expands north from Mexico to Canada from spring to summer, mainly across Great Plains and Southwest.



- Two aspects to future changes:
  - Earlier onset (left; most increase along northern margin)
  - Broader extent (right; core areas change little, but consensus increase on east, north, west sides of “hot spot”.

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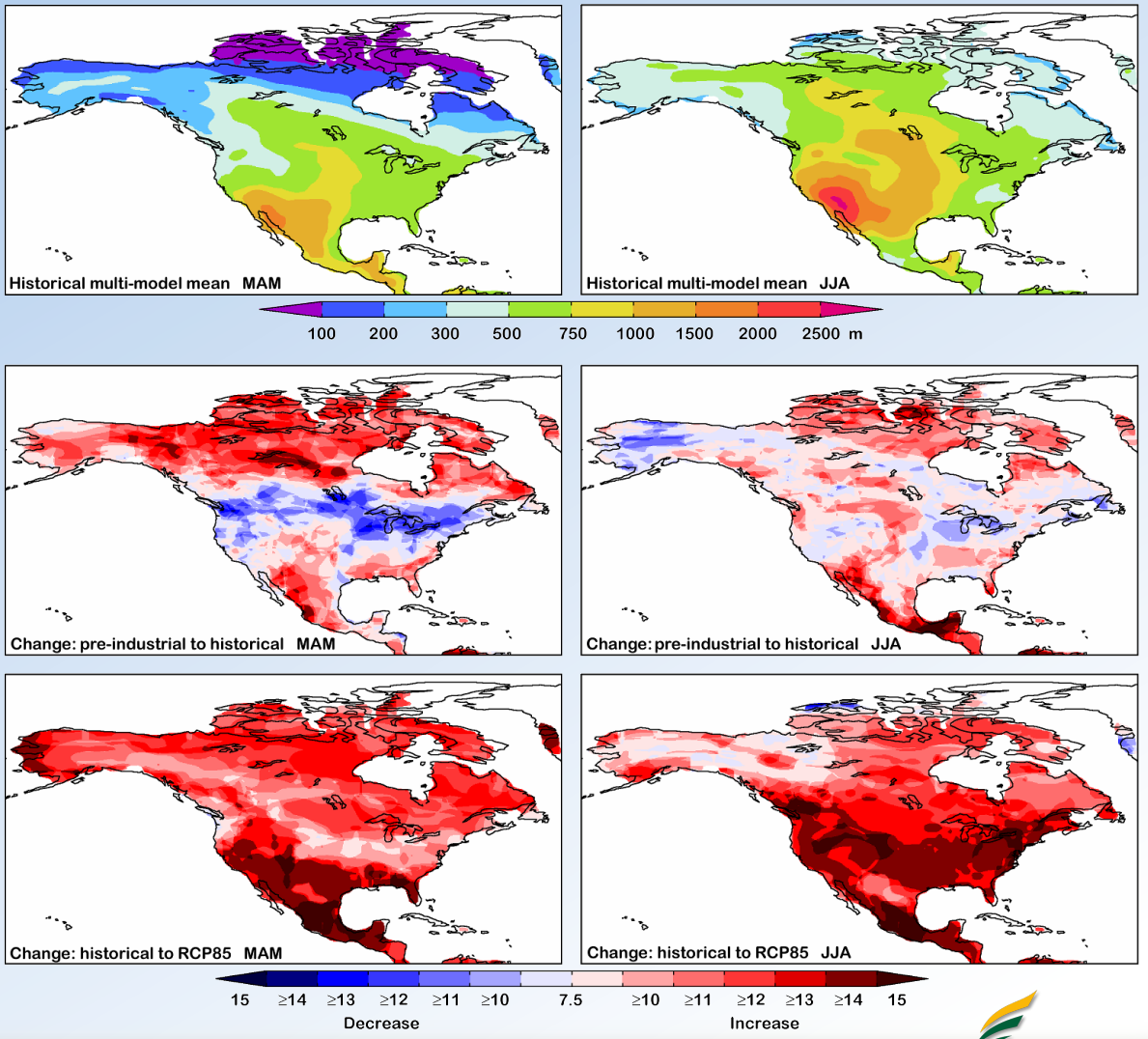
BL Depth (LCL)

- Past: decrease where industrial aerosols are (especially winter, spring), otherwise increase.
- Future: Consensus for deepening BL almost everywhere, as atmosphere warms, dew point depression increases.



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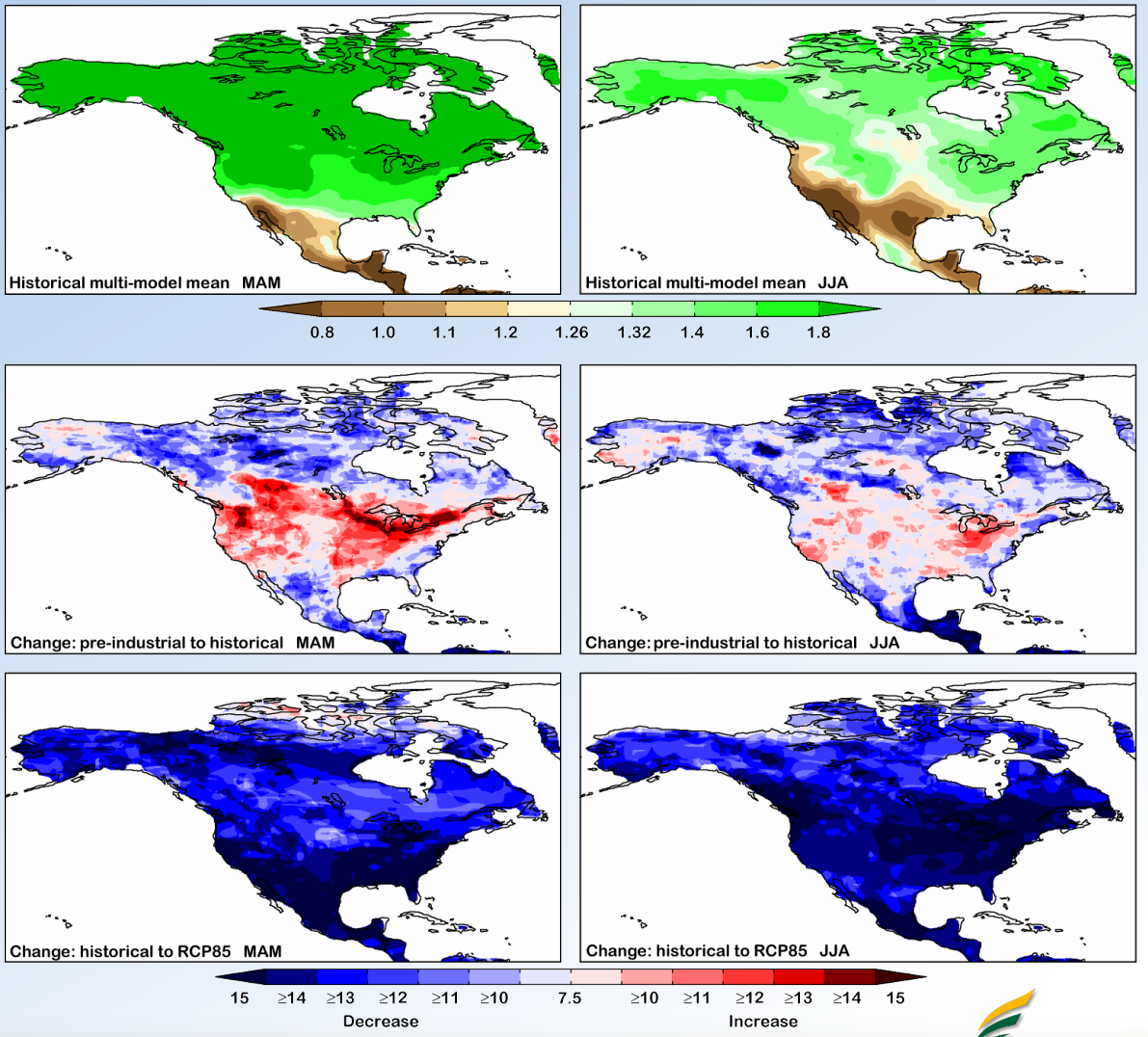
Priestley-Taylor Coefficient

$$\alpha = \left(\frac{\lambda E}{H + \lambda E}\right)\left(\frac{1+\varepsilon}{\varepsilon}\right), \quad \varepsilon = \frac{\lambda}{C_P}\frac{dq}{dT}\bigg|_{T_{LCL}}$$

- Decreasing α suggests entrainment at the top of the PBL has a reduced impact on boundary layer properties relative to surface fluxes.



Betts, 2004: *Bull. Amer. Meteor. Soc.*, **85**, 1673-1688, doi: 10.1175/BAMS-85-11-1673.

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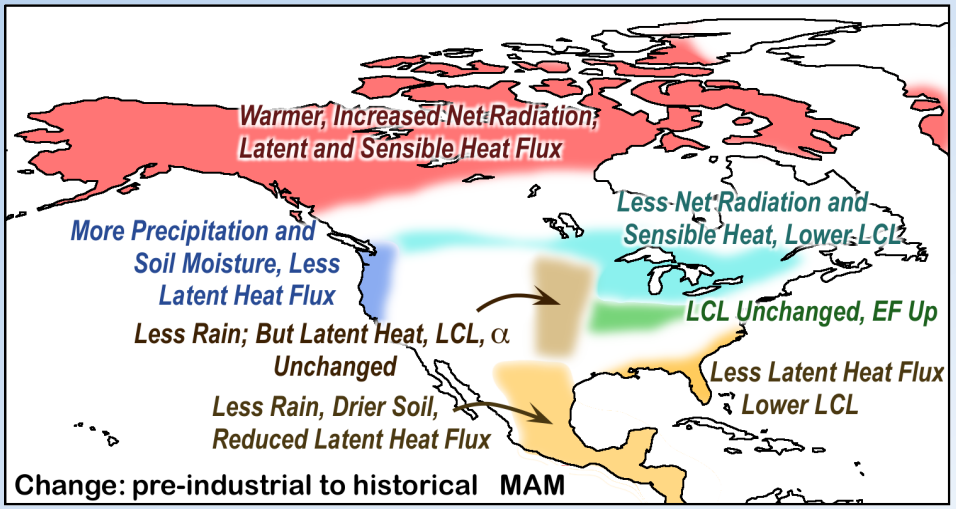
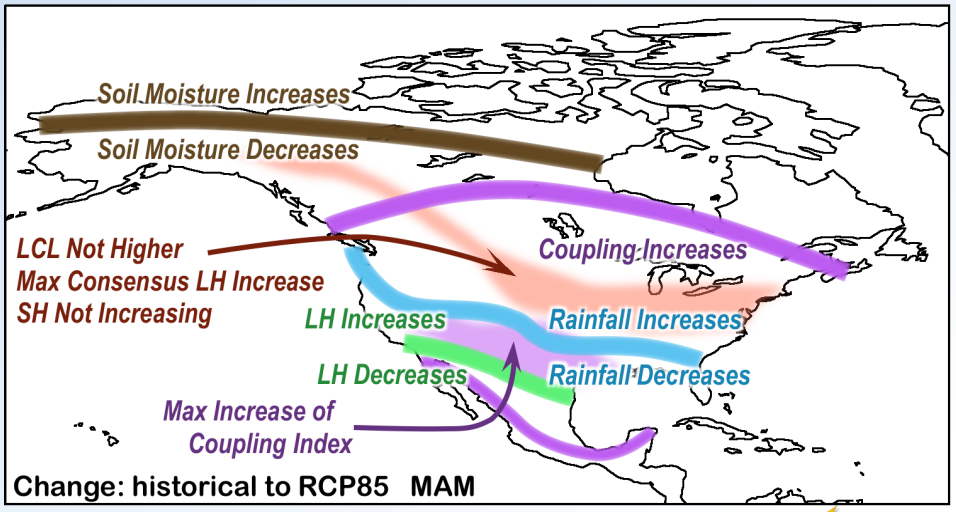
Synthesis: Spring

- Past: Arctic, subtropical responses consistent with initial global warming in GCMs
  - Aerosol impacts also evident.
  - Only discernable land use change signal is here over central U.S.
- Future: series of N-S dipoles in water cycle (SM, precip, evaporation)
  - Increase in L-A coupling coincides with ↓precip + ↑evap.





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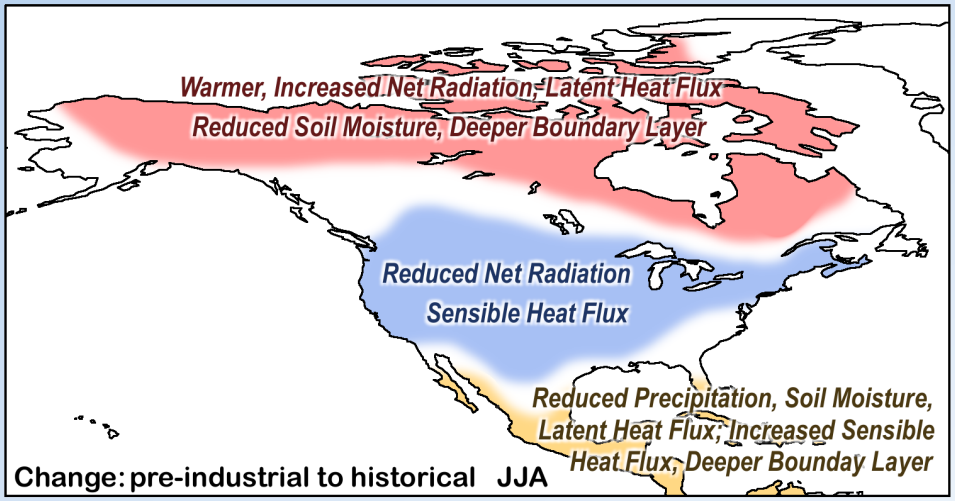
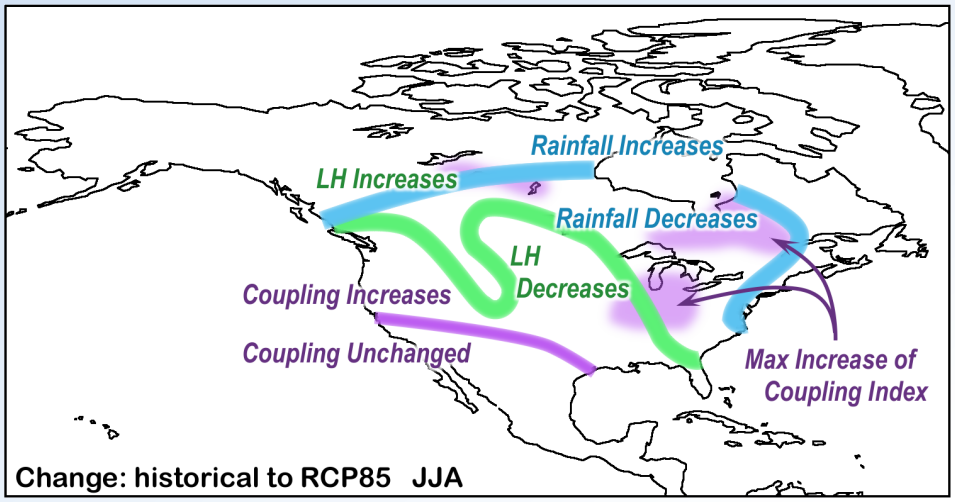
Summer:

- Simpler patterns.
- Past→present: aerosol and warming signals drive changes.
- Future: subtropical water cycle characteristics intensify, push poleward; more extremes and variability.





Outlook based on CMIP5 models

- Soil moisture increases in winter at high latitudes, drier in warm season / dry seasons (monsoon areas).
- Increase in extent, duration of soil moisture controls on surface fluxes (land-atmosphere coupling).
- Increase in land surface impact on PBL humidity & temperature, both in absolute terms and relative to entrainment from free atmosphere.
- Details of RCPs will have some effect on conclusions.

Dirmeyer, P. A., Y. Jin, B. Singh, and X. Yan, 2012a: *J. Hydrometeor.*, (in revision).
Dirmeyer, P. A., Y. Jin, B. Singh, and X. Yan, 2012b: *J. Climate*, (in revision).

Thank you!